3.1.2 Call Procedures

At each of the 18 stationary test points, the field test team placed an average of 40 test calls in digital mode. Calls were placed using an auto-dialer for a 30-second duration, followed by a 15 second break (total of 45 seconds / call). The call quality and system performance were monitored at the office location, and any anomalous events were noted[2].

For the Mobile Test Routes, identical call procedures were followed with one exception. Due to varying lengths of time required to complete the test routes, the routes were driven multiple times until approximately 100 calls had been placed. Mobile routes 1 and 2 both cover the northern section of the test region. Mobile route 1 was driven north-south and mobile route 2 was driven east-west. In order to ensure ubiquitous testing, Mobile route 1 and 2 were each driven for approximately 50 calls rather than 100 calls.

3.1.3 Data Collection & Storage Procedures

USWC collected and archived the following set of files during each day of testing:

- RadioCamera™ Base Unit files for each site in the test region;
- Mobile Test Unit Files:
    - SAFCO Log File (call events as reported by the SAFCO unit);
    - GPS Log File;
- RadioCamera™ Hub Files:
    - Playback Files;
    - Call Event Log File.

The *.csv files containing "best", "first" and "all" location measurements per call were provided to NENA at the end of testing. All files were available for review.

[2] Anomalous events included inadvertent switching between AMPS and digital modes, dropped calls, and equipment or procedural failures during testing.

4 PERFORMANCE ANALYSIS

4.1 Data Analysis Overview

A complete statistical analysis of the test data has been performed, and the results are reported in the Section 5. Specific data file formats and content are described further in Section 4.2.

Post-processing software was used to select specific location measurements to represent the **First Fix** and **Best Fix** location estimates for each test call. The "best fix" selection was based on a quality factor associated with the location measurements (this quality factor is also reported in the output files).

4.1.1 All Fixes

All Fix accuracy represents unfiltered accuracy measurements. In All Fix data, the accuracy of all location fixes are reported, representing 100% yield where no fixes are discarded regardless of fix or call quality. Approximately 10 fixes are recorded for each test call (one every 3 seconds, for each 30-second call).

4.1.2 First Fix

First Fix accuracy represents the accuracy for the first location fix of each call, 1 fix / call. As an E9-1-1 design goal, the first fix was to be reported within 4 seconds of call initiation. To meet this goal, the RadioCamera™ system was configured to collect the RF signal over a 2.5 second interval. Subsequent processing required approximately 0.5 second, resulting in a first fix availability within ~3.2 seconds. First Fix location estimates are indicative of PSAP call routing accuracy.

4.1.3 Best Fix

Best Fix measurements represent the accuracy for the highest quality fix during each call, 1 fix / call. The Best Fix measurement is chosen as the fix with the highest associated quality factor for the duration of a call. The Best Fix location estimate is reported within 30 seconds as per the FCC recommendations and is used to assess overall FCC accuracy compliance.

4.1.4 Accuracy Analysis

Accuracy has been determined using a fully redundant GPS unit augmented with a dead-reckoning system. Once the Best Fix location estimates were determined, a comprehensive accuracy analysis was conducted. This analysis included:

- Statistical analysis to estimate a Probability Density Function (PDF) and Cumulative Distribution Function (CDF) for each test case (*i.e.*, a Stationary Test Point or Mobile Test Route),
- Determination of the 67^{th} and 95^{th} percentile accuracy performance, as per FCC requirements, for each test case,
- Statistical analysis for groups of test cases (e.g., mobile, stationary, etc.),
- Final statistical analysis for the overall test performance.

All performance results have been summarized and are presented in Section 5.

4.2 Data Files

Three data files were generated containing the final post-processed location results. These files are briefly described as follows:

- **First Fix File** – this file contains location information representing the first fix location measurement;

- **Best Fix File** – this file contains the best location measurement fix obtained for the duration of each call;

- **All Fix File** – this file contains all fixes for all calls at a given test point or test route. This file represents the unfiltered[3] output of the RadioCamera™ system.

The RadioCamera™ network was configured to provide 100% yield on all test calls. First fix and best fix location information is reported for every call, regardless of the quality of the location estimate.

4.2.1 Output File Formats

Each file was named according to the following convention:

- First Fix File: XSS_T01_VY_ZZZZ_FIRST.CSV
- Best Fix File: XSS_T01_VY_ZZZZ_BEST.CSV
- All Fix File: XSS_T01_VY_ZZZZ_ALL.CSV

Where X is the type of test (S for stationary, M for mobile), SS is the test point or mobile route number, V stands for visit, Y is the visit number (always 1 for this audit) and ZZZZ is the 24-hour timestamp. The CSV extension represents the comma-delimited format readable by Excel. The data format for all files is described in Table 2.

Table 2: Output file format.

FIELD	NAME	DESCRIPTION
1	Loc_ID	Unique number using the format XSS
2	Fix_time	Time of location fix, accurate to within 1/10 second
3	Seq_Num	Sequence number of location fixes for a given call
4	Lon_Est	RadioCamera™ estimated longitude, WGS 84, decimal degrees with 6 digits of precision after decimal point
5	Lat_Est	RadioCamera™ estimated latitude, WGS 84, decimal degrees with 6 digits of precision after decimal point
6	Lon_True	Ground true longitude from GPS unit with dead-reckoning system WGS 84, decimal degrees with 6 digits of precision after decimal point
7	Lat_True	Ground true latitude from GPS unit with dead-reckoning system, WGS 84, decimal degrees with 6 digits of precision after decimal point
8	Delta	Accuracy error, difference between the RadioCamera™ estimated location and the GPS system location in meters
9	Sens_Count	Number of RBU sensors contributing to a fix
10	Lq_Factor	0 - 99 (poor to excellent)

[3] In this report, the RadioCamera™ "yield" for All Fix data is 100%. That is, the data is not filtered based upon the confidence measure, and all fixes are reported regardless of the quality.

The time stamp that is used is GPS CentiSeconds, where GPS seconds is the number of seconds elapsed since midnight Sunday morning in GPS Time.

4.3 Post-Processing

The RadioCamera™ real-time processing used during testing was designed to facilitate live testing and audit of the system performance. As such, the test system was configured to process, display and store all data – regardless of the data integrity or the quality of the location estimates. In addition, no results are displayed indicating which estimates might be selected as the "first" or "best" fix locations. Therefore, post-processing analysis is required to demonstrate the complete performance of the overall system.

In general, the post-processing techniques employed in this analysis were designed to address data filtering. Data filtering was required to select final outputs based upon the location quality estimates, or confidence factors.

5 PERFORMANCE RESULTS

Accuracy performance results of the system are presented in this section. Overall, mobile and stationary performance results are presented in Figure 12 – Figure 14. In the (a) figures, the percentage of location fixes that fall within the 100 meter and 300 meter requirements is shown for best fix, first fix and all fixes. In the (b) figures, the error in meters for 67% and 95% of calls is shown for best fix. Recall that the current FCC mandate requires network-based location technologies must place 67% of best fixes within 100 meter of the caller and 95% of best fixes within 300 meter.

Overall, combined mobile and combined stationary performance results are shown in Table 3 – Table 5.

Table 3: Overall Performance Summary for all combined mobile and stationary test cases.

	# of Calls	m@67%	m@95%	%<100m	%<300m
Best Fix	1481	61m	295m	81%	95%
First Fix	1481	60m	364m	79%	94%
All Fixes	1481	62m	348m	81%	94%

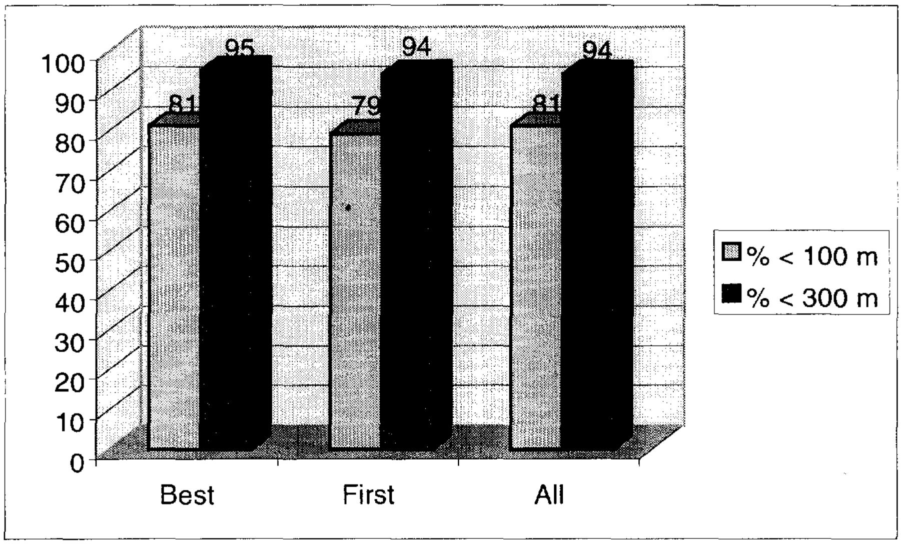
Table 4: Mobile Performance Summary for all mobile test cases.

	# of Calls	m@67%	m@95%	%<100m	%<300m
Best Fix	782	50m	209m	88%	96%
First Fix	782	42m	469m	85%	93%
All Fixes	782	50m	333m	86%	94%

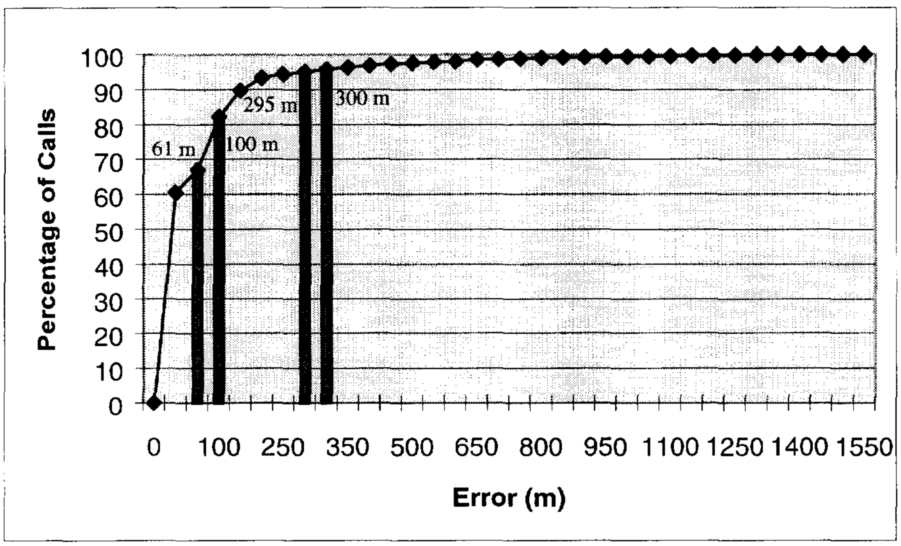
Table 5: Stationary Performance Summary for all stationary test cases.

	# of Calls	m@67%	m@95%	%<100m	%<300m
Best Fix	699	83m	327m	74%	94%
First Fix	699	87m	326m	72%	94%
All Fixes	699	85m	360m	74%	94%

Figure 12: Overall Accuracy Performance (9 mobile test routes and 18 stationary test points)

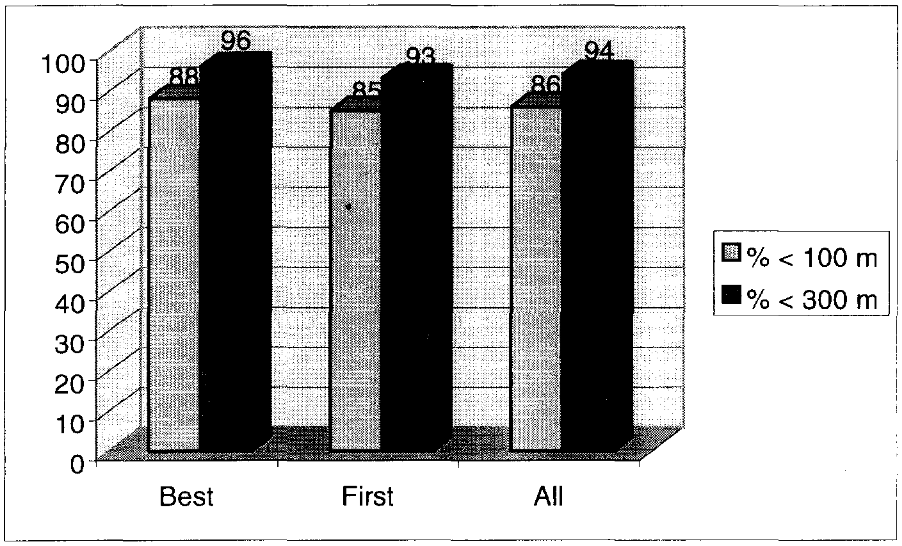


(a) Percentage of calls with accuracy errors less than 100 m and 300 m for "Best Fix," "First Fix" and "All Fix" results.

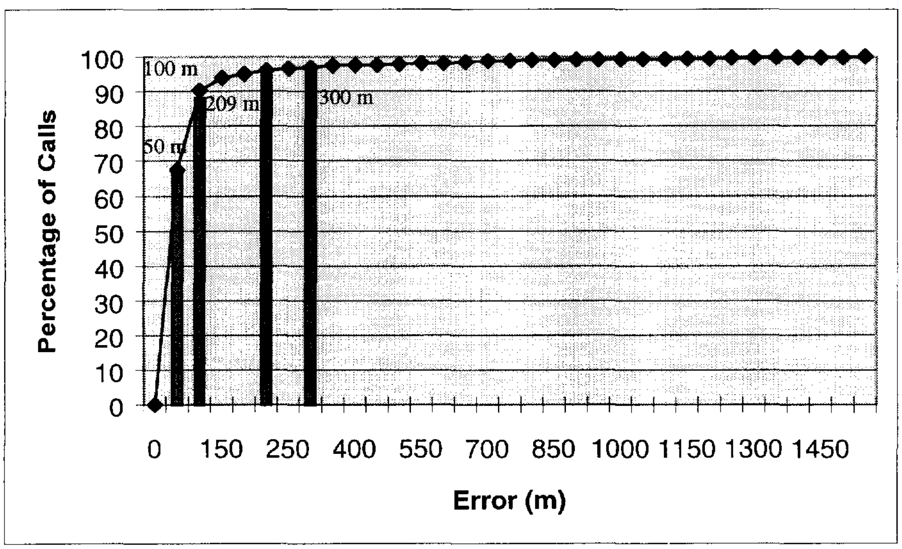


(b) "Best Fix" accuracy error in meters with respect to percentage of calls (67% = 61 m, 81% = 100m, 95% = 295 m, 95.3% = 300 m).

Figure 13: Mobile Accuracy Performance (9 mobile test routes)

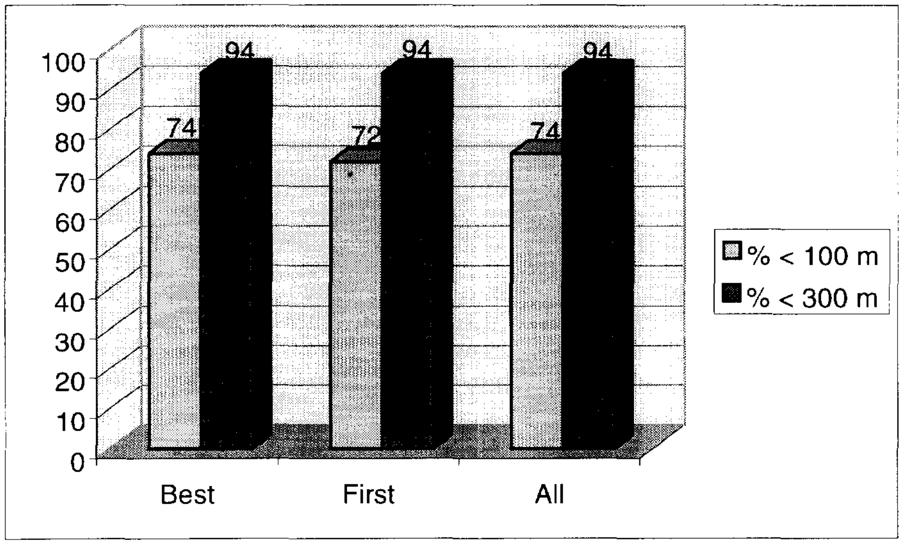


(a) Percentage of calls with accuracy errors less than 100 m and 300 m for "Best Fix," "First Fix" and "All Fix" results

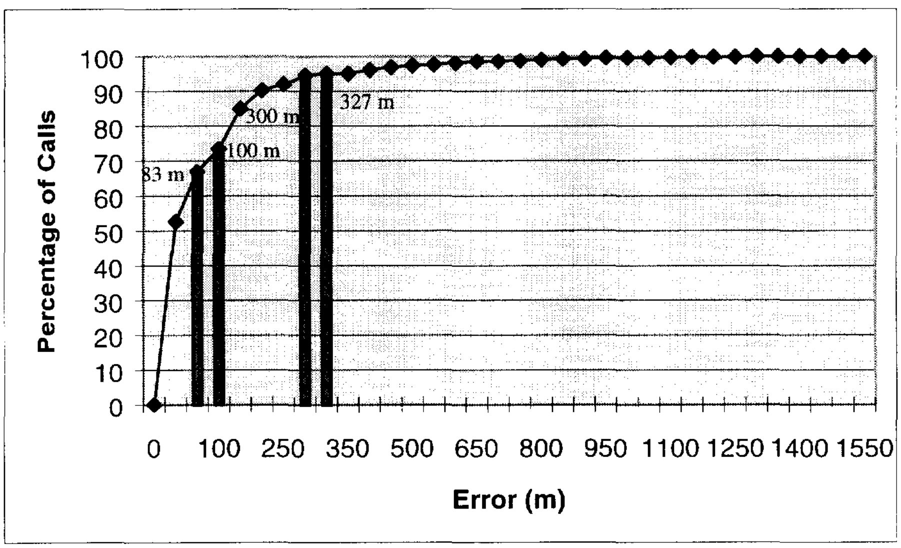


(b) "Best Fix" accuracy error in meters with respect to percentage of calls (67% = 50 m, 88% = 100m, 95% = 209 m, 96% = 300 m).

Figure 14: Stationary Accuracy Performance (18 test points).



(a) Percentage of calls with accuracy errors less than 100 m and 300 m for "Best Fix," "First Fix" and "All Fix" results.



(b) "Best Fix" accuracy error in meters with respect to percentage of calls (67% = 83 m, 74% = 100m, 94% = 300 m, 95% = 327 m).

Additional insight may be gained into the nature of the system performance by observing the histograms of the Best Fix error for the mobile and stationary data within the test region, as shown in Figure 15 – Figure 16.

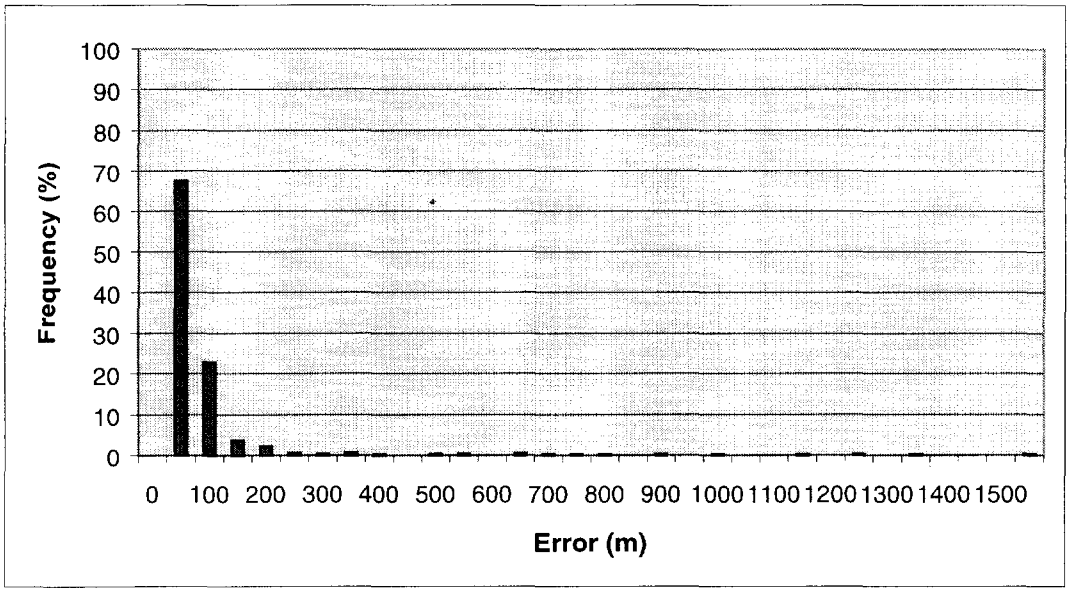


Figure 15: Histogram – Mobile Test Data (9 Routes), Best Fix Performance.

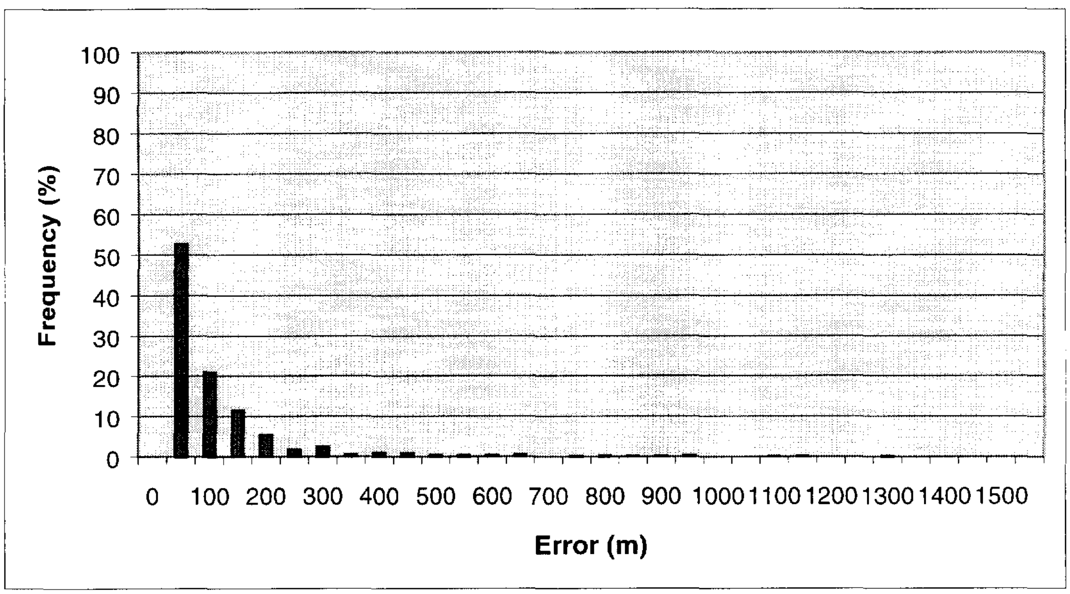


Figure 16: Histogram – Stationary Test Data (18 points), Best Fix Performance.

A detailed description of the individual performance results for each test case (mobile test routes and stationary test points) is presented in Table 6 – Table 9

Table 6: Mobile Testing Performance, percentage of calls with accuracy errors less than 100 m and 300 m.

		BEST FIX		FIRST FIX		ALL FIXES	
ID / TYPE	# of Calls	%<100m	%<300m	%<100m	%<300m	%<100m	%<300m
M1	43	93%	95%	93%	100%	92%	95%
M2	44	91%	91%	86%	91%	88%	90%
M3	95	95%	99%	94%	96%	96%	99%
M4	98	84%	98%	79%	93%	85%	96%
M5	83	89%	94%	81%	90%	85%	90%
M6	102	88%	97%	78%	94%	86%	96%
M7	110	93%	96%	90%	92%	90%	94%
M8	106	71%	92%	81%	90%	66%	90%
M9	102	95%	100%	89%	96%	92%	97%
All	782	88%	96%	85%	93%	86%	94%

Table 7: Mobile Testing Performance, accuracy errors in meters for 67% and 95% of calls.

		BEST FIX		FIRST FIX		ALL FIXES	
ID / TYPE	# of Calls	m@67%	m@95%	m@67%	m@95%	m@67%	m@95%
M1	43	43m	107m	32m	105m	39m	234m
M2	44	51m	609m	40m	605m	50m	745m
M3	95	38m	88m	33m	201m	35m	81m
M4	98	64m	190m	53m	367m	59m	261m
M5	83	43m	326m	43m	837m	45m	739m
M6	102	42m	257m	50m	335m	48m	280m
M7	110	55m	139m	32m	687m	50m	373m
M8	106	89m	654m	46m	703m	102m	661m
M9	102	44m	95m	41m	224m	44m	138m
All	782	50m	209m	42m	469m	50m	333m

Table 8: Stationary Testing Performance, percentage of calls with accuracy errors less than 100 m and 300 m.

		BEST FIX		FIRST FIX		ALL FIXES	
ID / TYPE	# of Calls	%<100m	%<300m	%<100m	%<300m	%<100m	%<300m
S1	42	95%	100%	95%	100%	96%	100%
S2	35	67%	97%	60%	97%	64%	97%
S3	30	97%	97%	97%	97%	97%	97%
S4	40	38%	73%	50%	88%	49%	83%
S5	42	50%	91%	48%	91%	46%	88%
S6	41	22%	85%	24%	83%	23%	79%
S7	46	78%	91%	67%	87%	78%	89%
S8	42	86%	98%	79%	93%	83%	99%
S9	47	81%	100%	81%	98%	80%	99%
S10	41	71%	98%	78%	95%	76%	96%
S11	45	69%	91%	64%	89%	67%	91%
S12	39	92%	100%	97%	100%	91%	99%
S13	43	100%	100%	98%	98%	99%	99%
S14	43	81%	88	91%	93%	81%	87%
S15	43	47%	100%	305	100%	41%	100%
S16	18	78%	100%	78%	100%	81%	100%
S17	36	100%	100%	97%	100%	100%	1005
S18	27	89%	96%	82%	93%	86%	95%
All	699	74%	94%	72%	94%	74%	94%

Table 9: Stationary Testing Performance, accuracy errors in meters for 67% and 95% of calls.

		BEST FIX		FIRST FIX		ALL FIXES	
ID / TYPE	# of Calls	m@67%	m@95%	m@67%	m@67%	m@67%	m@95%
S1	42	54m	81m	54m	97m	54m	86m
S2	35	91m	183m	121m	183m	121m	183m
S3	30	38m	49m	38m	49m	38m	49m
S4	40	210m	646m	143m	604m	143m	646m
S5	42	136m	415m	144m	354m	144m	440m
S6	41	200m	433m	222m	1105m	240m	1139m
S7	46	54m	701m	93m	777m	65m	701m
S8	42	36m	186m	64m	585m	36m	188m
S9	47	31m	295m	21m	295m	31m	295m
S10	41	37m	161m	37m	270m	37m	270m
S11	45	70m	443m	119m	524m	78m	510m
S12	39	58m	108m	42m	85m	66m	134m
S13	43	51m	55m	51m	81m	51m	55m
S14	43	85m	360m	64m	360m	91m	364m
S15	43	113m	113m	113m	113m	113m	113m
S16	18	85m	106m	85m	106m	85m	106m
S17	36	36m	36m	36m	50m	36m	50m
S18	27	48m	133m	73m	623m	73m	133m
All	699	83m	327m	87m	326m	85m	360m

6 CONCLUSIONS

NENA and US Wireless Corporation have successfully completed testing of the RadioCamera™ Wireless Location system. Nine days of field-testing have been completed in a 2 square mile test region, involving over 1400 test calls and 16,000 location fixes. The performance capabilities of the RadioCamera™ system have been characterized over a wide range of operating environments and test conditions. The system was able to meet and exceed the FCC accuracy requirement for ensuring that at least 67% of all location fixes were within 100 meters of the caller's location and 95% are within 300 meters.

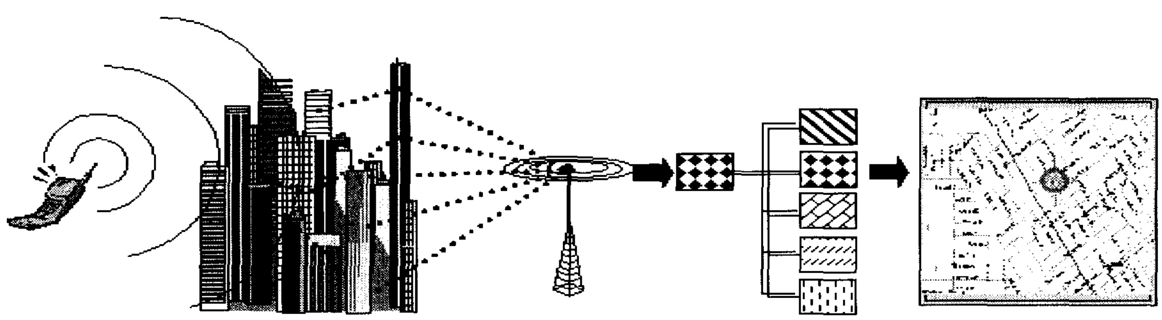
APPENDIX A: RADIOCAMERA™ SYSTEM TECHNICAL BRIEF

Location Pattern Matching Theory

The U.S. Wireless RadioCamera™ (RC) system employs Location Pattern Matching technology to determine the location of a caller's mobile device. This technology, based on Radio Frequency (RF) signal pattern recognition theory, is illustrated in Figure 17 below.

Natural and man-made objects cause the mobile phone's signal to separate into a number of signals following different paths (multipath). RF signals from a given geographic location have a distinct set of multipath features by the time they reach the RC System antenna array, as shown in Figure 18. Key features of these signals are detectable and processed into a signal pattern signature. The system identifies the multipath signature emitted by a caller's cell phone and compares that signature to a database containing signatures previously recorded from known locations. Since the signal pattern generated from a mobile phone is uniquely specific to the phone's location, the signature match is unique and identifies the location of the caller's transmitter.

The matching process involves several layers of signal processing and pattern recognition accomplished in real-time, with continual generation of location estimates every few seconds throughout the observation of the caller's signal. This establishes the velocity and track of the mobile device.



1. A call placed from a mobile cell phone emits radio signals.

2. The signals bounce off of buildings and other obstacles, reaching the system antennae via multiple paths.

3. The RadioCamera™ system analyzes the unique characteristics of the signal, including its multipath pattern, and creates a signal pattern signature.

4. The signature is compared to a database of signatures from known locations, and a match is made, and the caller's geographic location is identified.

Figure 17 - Location Pattern Matching Geolocation

This process is not computationally burdensome and the database is typically installed on a commercial grade PC running a *Windows NT* operating environment.

RadioCamera technology extracts information from radio wave fronts only, independent of the modulation of the radio signal. Therefore, RC technology is compatible with all leading analog and digital wireless standards. The RC System is not limited due to multipath, line of sight, or multiple base station triangulation issues, as are older wireless geolocation technologies. The performance of TDOA, AOA, and GPS systems is significantly degraded when challenged in dense urban environments with high multipath content, where approximately 70% of all mobile phone calls originate. U.S. Wireless has developed an entirely new method of wireless geolocation that turns older system liabilities into real advantages. The RC System performance is enhanced in high multipath areas because the greater number of multipath signals provides a more distinctive location RF signature.

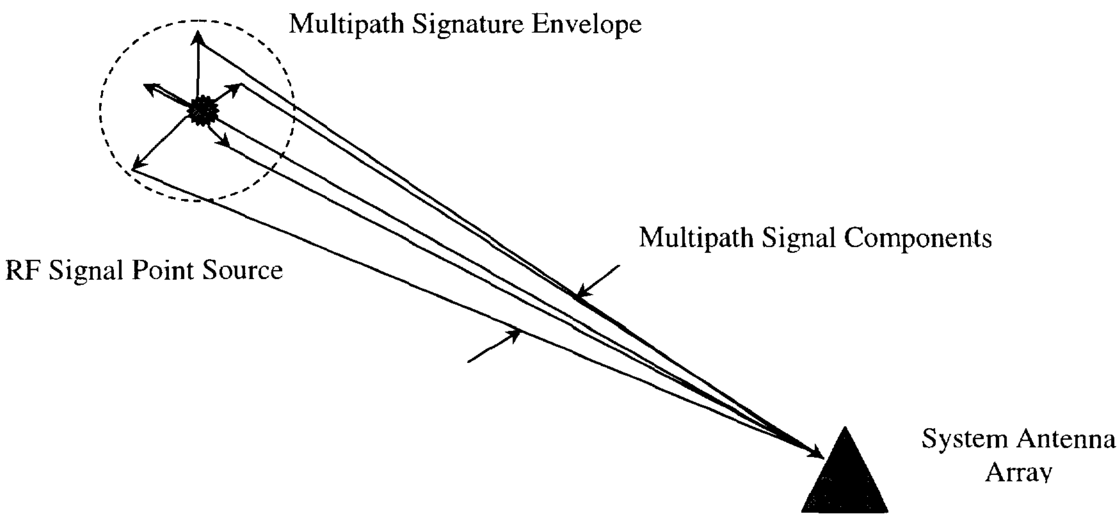


Figure 18- Multipath RF characteristics that define RF signatures

RadioCamera System Processing

The RadioCamera System uses processing algorithms that characterize RF signal amplitude and phase differences as received at an array of antennas. A sophisticated matching algorithm that incorporates soft-decision making as well as ambiguity mitigation is used to match a received signature to a database of known signatures. A single RBU receiving site is capable of fully locating signal sources. However, greater geolocation accuracy is obtained by combining readings from multiple RadioCamera sites.

In order to determine the location of a mobile device transmitter–to geolocate the caller–two main modes of operational processes must be performed:

Calibration	Move a calibration transmitter through the coverage area. Record the position of the transmitter by an independent GPS-based system. Convert calibrated signals into signatures. Combine the signatures with their location of origin in a Calibration Table (Cal Table) database.
Location	Receive the multipath signals from an unlocated transmitter in the coverage area.

Convert the signals into signatures under controlled conditions.
Matching the transmitter signature to the closest Cal Table signatures.
Determine the associated location of the transmitter.

Before real-time geolocation of callers can take place, a Cal Table is constructed from RF signal signatures generated from known locations in the coverage area (during Calibration Mode operation). The reference database, containing entries of signature / location, is very robust and stable for extended periods of time, and immune to conditions of weather, vehicular traffic, etc. Re-calibration of the Cal Table is expected to occur only once or twice a year, and will be provided as an integral part of the US Wireless service bureau offering.

When actually geolocating callers (during Location Mode operation), RF signals are acquired on the uplink at a RadioCamera Base Unit (RBU). RF sampling and digitization of the signal is followed by processing and generation of a RF signature.

The Cal Table and matching reside in the centralized Location Processor (LP) unit. After the RBU generates a signature for an unlocated mobile device, the signature is then sent to the LP, where it is matched in the Calibration Table database (Cal Table) specific to the RBU. The resulting locations are then processed for a final location determination. Figure 19 provides a high-level block diagram of the RadioCamera™ Wireless Location Platform.

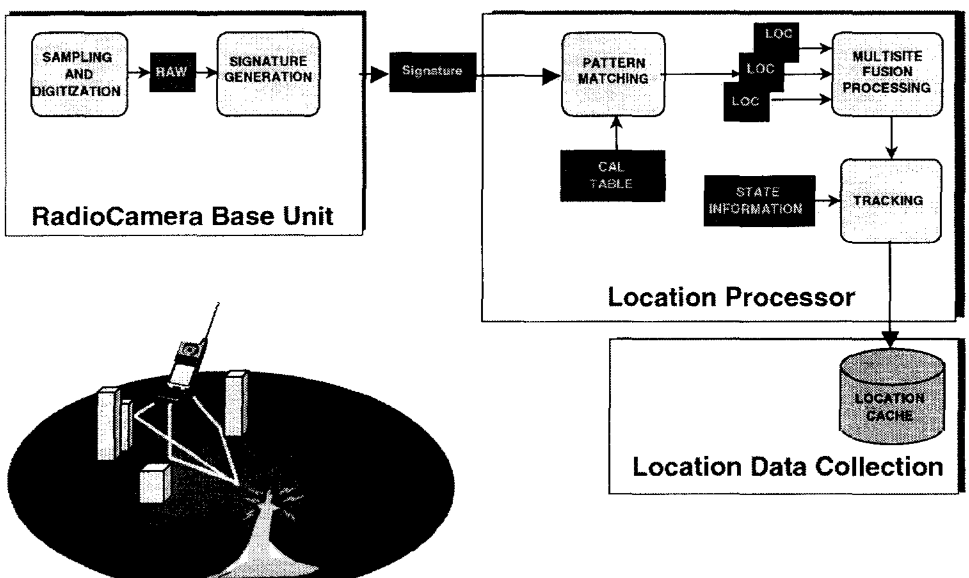


Figure 19 - RadioCamera™ Wireless Location Platform

The location matches from all reporting RBUs are then evaluated together in the multi-site matching Fusion Process. Here a small number of the most likely locations in the coverage area are determined. The single best final location is determined by using the history of the mobile device movement to rule out the least likely location estimates.

Tracking capabilities further enhance system accuracy. A tracking filter system reduces the error and ambiguity of a reported position by evaluating the current location estimates with previous estimates. In a model-based tracking approach, the RadioCamera™ Location Platform uses state information (position, speed, bearing) to allow only those solutions that are physically possible. Starting at the last known position, speed and acceleration limits of the cell phone are applied to eliminate improbable solutions. The tracking system also predicts the most likely track, based on statistical analysis of past known positions. This method of processing allows unprecedented accuracy that is vital in the highly mobile, fast changing cellular arena.